DOE's Vehicle Technologies Office

Energy Efficient Mobility Systems

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

David L. Anderson
Technology Development Manager
Office of Energy Efficiency and Renewable Energy

MOBILITY IS FOUNDATIONAL TO OUR WAY OF LIFE

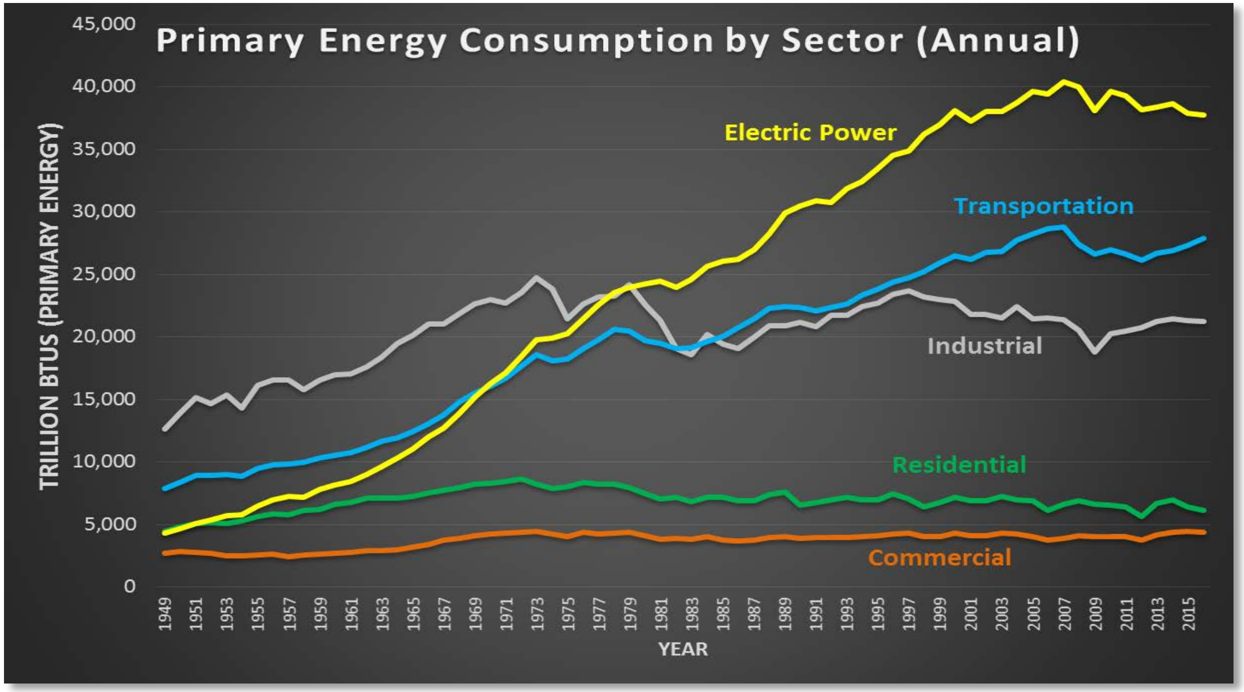





Graphics from highwaysindustry.com, mhlnews.com, fhwa.dot.gov, wmata.com, usatoday.com, maritime-connector.com, muffingroup.com, digitaltrends.com, sfmta.com, teslarati.com.

MOBILITY IS A LARGE PART OF OUR ENERGY ECONOMY

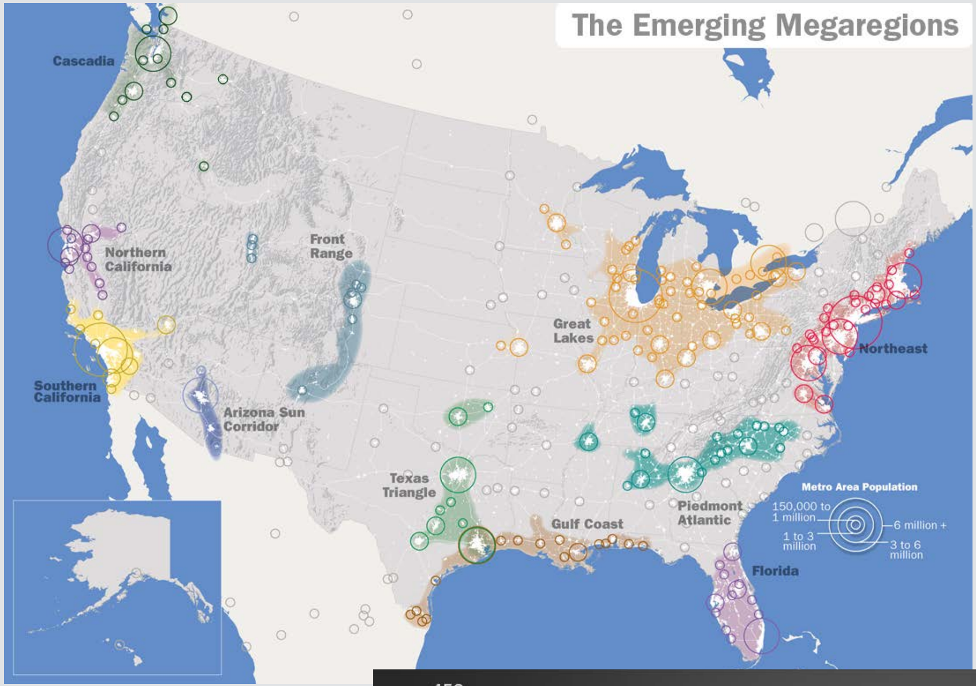
Transportation is the **2nd** largest expense for U.S. households



70% of total U.S. petroleum usage is for transportation

On-road vehicles account for **85%** of transportation petroleum usage

TRENDS SHAPING MOBILITY – POPULATION

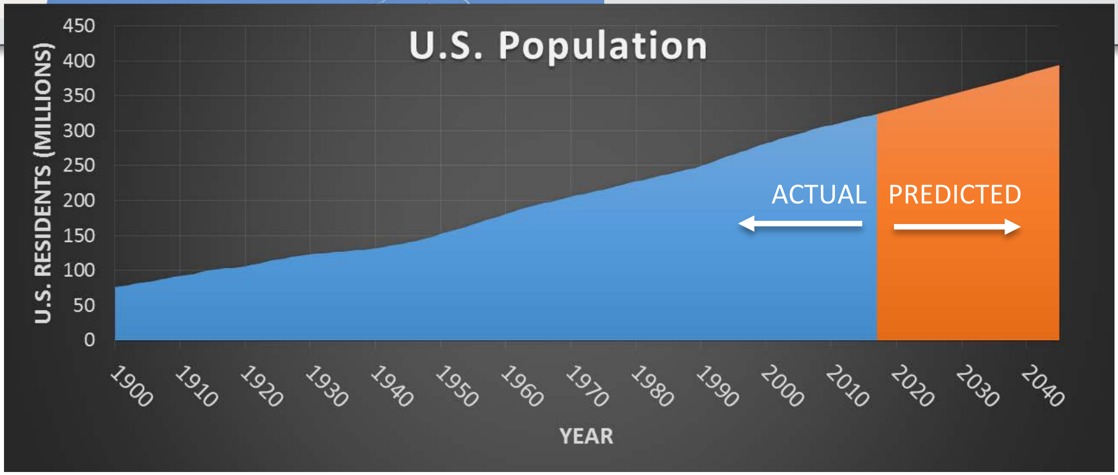


Megaregions & Shifts in Population Centers

11 megaregions are linked by transportation, economics, and other factors.

They represent over **75%** of our population and employment.

Population is expected to grow by **70 million people** in the next **30 years**.



Graphics and data from Regional Plan Association and U.S. Census Bureau.

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

TRENDS SHAPING MOBILITY – POPULATION

Each Year, Traffic Congestion Costs Us:

Time

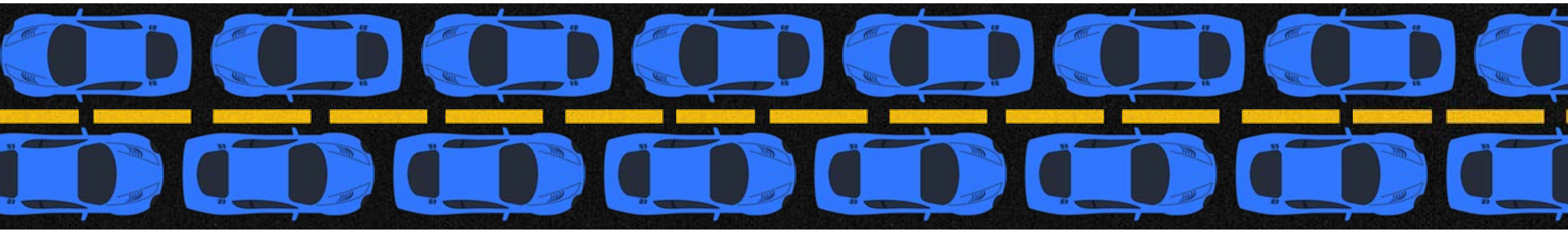
6.9 Billion Hours

Fuel

3.1 Billion Gallons

Money

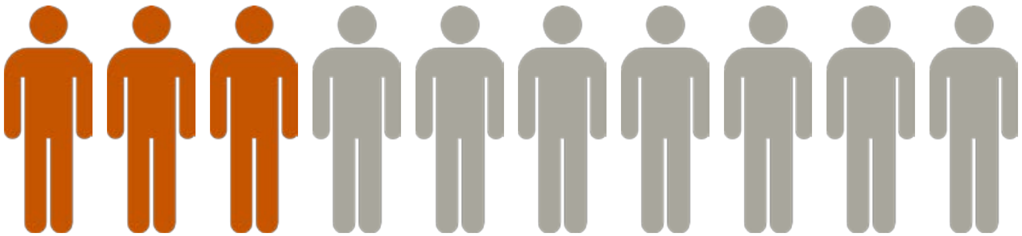
$160 Billion



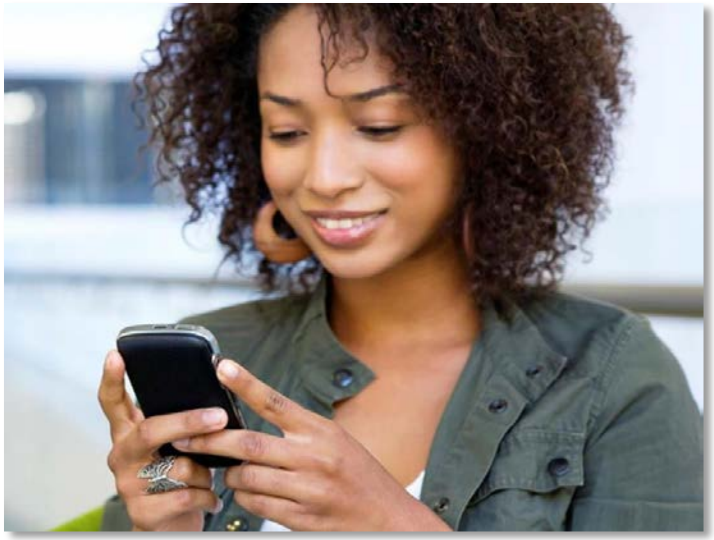
Data from Schrank, B., Eisele, B., Lomax, T., and Bak, J. (2015). 2015 Urban Mobility Scorecard. Technical report, Texas A& M Transportation Institute..

TRENDS SHAPING MOBILITY – DEMOGRAPHICS

Americans are Living Longer

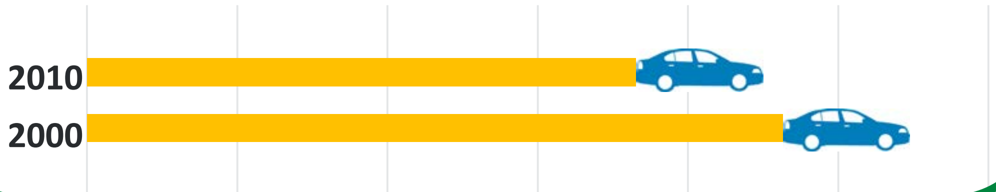


By 2045, the number of Americans over age 65 will increase by **77%**. About **one-third** have a disability that limits mobility.



Millennials are Connected & Influential

There are **73 million** Americans aged 18 to 34, and they drove **20% fewer miles** in 2010 than at the start of the decade.



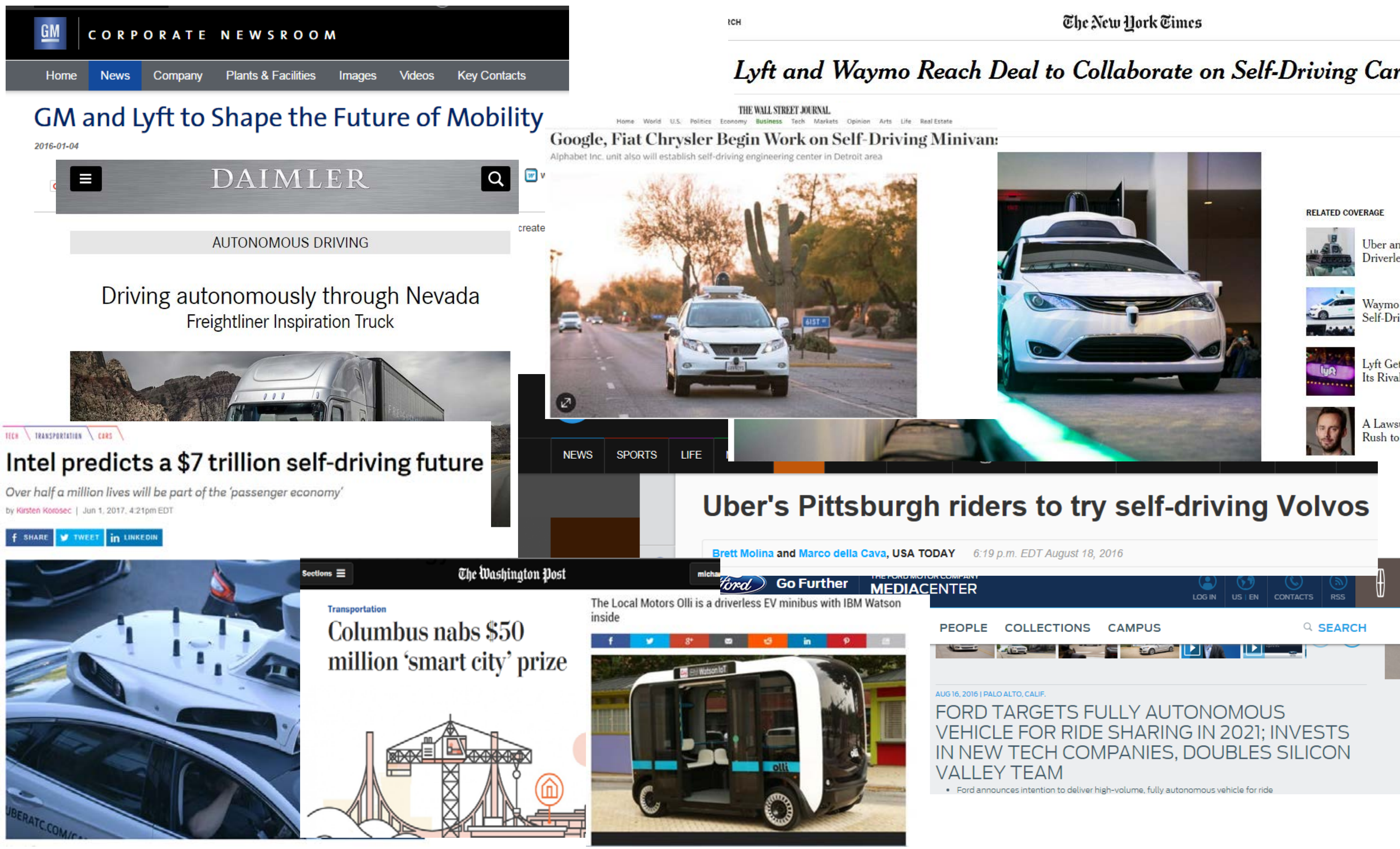
Data from U.S. DOT's Beyond Traffic, EY Megatrends (http://www.ey.com/Publication/vwLUAssets/ey-megatrends-report-2015/$FILE/ey-megatrends-report-2015.pdf), http://www.csc.com/cscworld/publications/135623/135624-connected_cars_drive_value.

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

TRENDS SHAPING MOBILITY – TECHNOLOGY

- Advancements in Vehicle Powertrain Technology
- Shift Toward Lightweight Materials
- Integration of Automated & Connected Vehicles
- Deeper Application of Big Data
- Faster Processing Speeds at Decreasing Cost

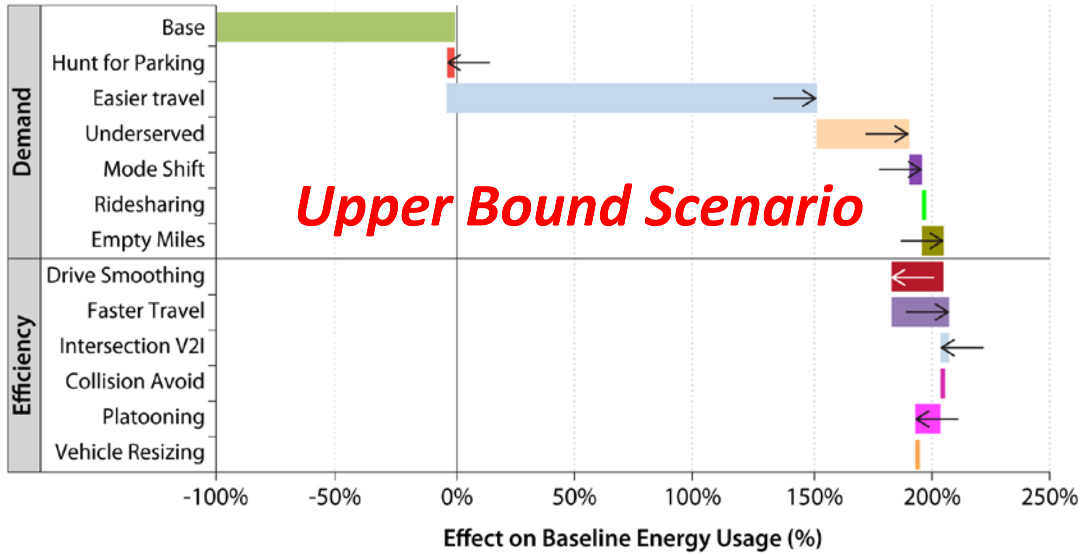
TRENDS ARE CAUSING A FUNDAMENTAL DISRUPTION



FUNDAMENTAL DISRUPTION, DRAMATIC ENERGY IMPACTS

+200%

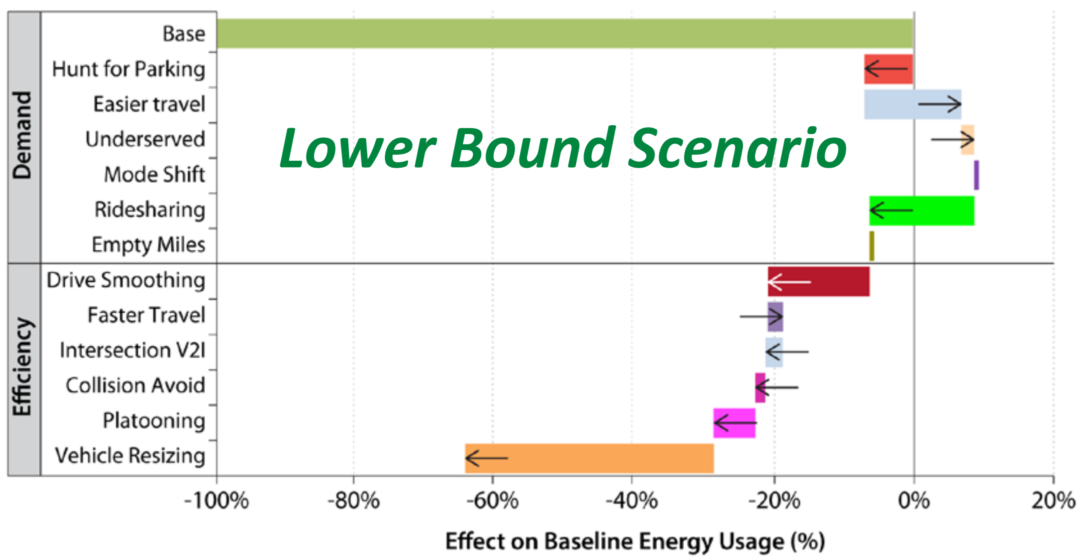
Potential Increase in Energy Consumption



2050 Baseline Energy Consumption

Potential Decrease in Energy Consumption

-60%



<u>*Source*</u>*:* Joint study by NREL, ANL, and ORNL
http://www.nrel.gov/docs/fy17osti/67216.pdf

FUNDAMENTAL DISRUPTION IN TRANSPORTATION

- ***Transportation*** is changing
- ***Mobility*** is changing
- The ***questions*** are changing
- The ***solutions*** are changing
- ***VTO*** is changing to meet increasingly complex energy and mobility needs

How will disruptive forces in the mobility landscape affect energy consumption in the future?

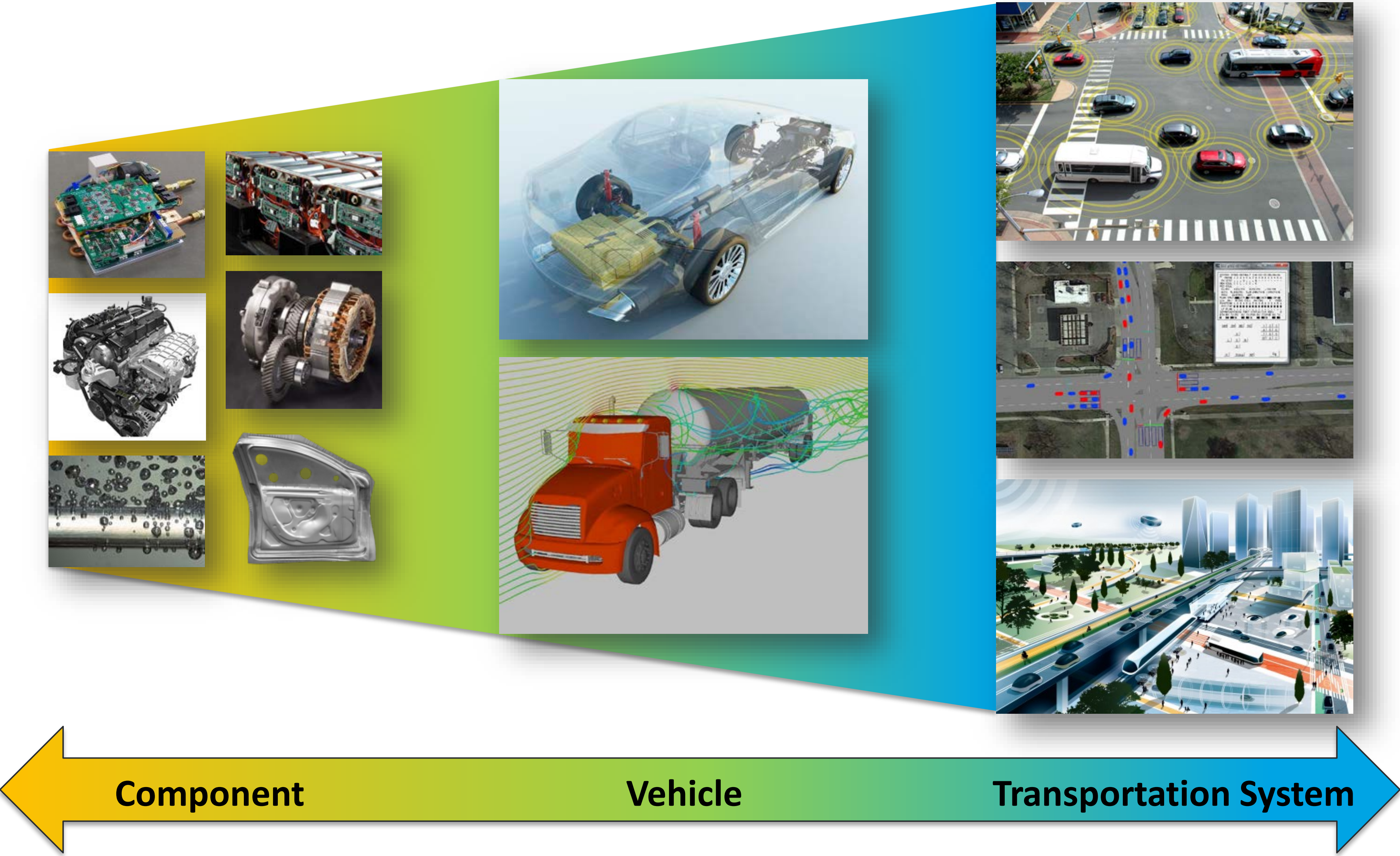
What opportunities exist to enable and/or encourage deep gains in energy efficiency?

What are the most promising system-level innovations that provide the biggest levers?

How can we better understand and leverage how travelers make mobility decisions?

How can we better support and encourage a maximum-mobility, minimum-energy future?

VTO EXPANDING FOCUS TO TRANSPORTATION LEVEL

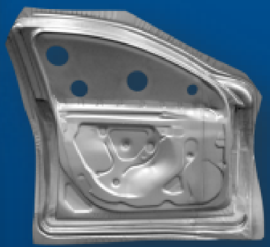


EERE'S VEHICLE TECHNOLOGIES OFFICE (VTO)

Vehicle Technologies Office

Electrification

Materials Technology



Advanced Combustion Systems & Fuels

Energy Efficient Mobility Systems

Deployment

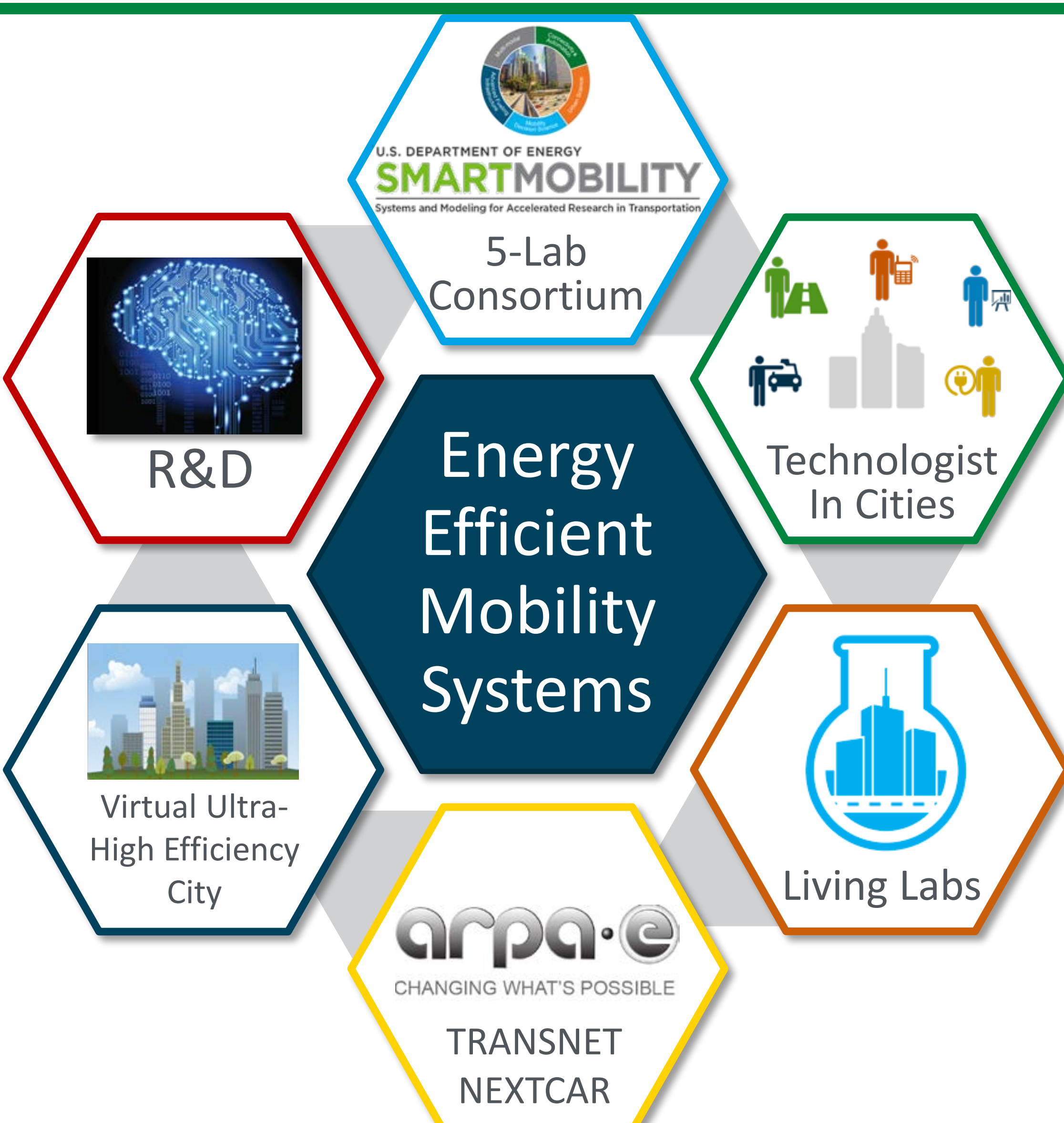
Clean Cities

Analysis, Comms, & Operations

VTO develops advanced transportation technologies that:

- ✓ Improve energy ***efficiency***
- ✓ Increase domestic energy ***security***
- ✓ Reduce operating ***cost*** for consumers & business
- ✓ Improve global ***competitiveness*** of US economy

ENERGY EFFICIENT MOBILITY SYSTEMS (EEMS)



EEMS will identify and support technologies and innovations that encourage a ***Maximum-Mobility, Minimum-Energy Future.***

SMART MOBILITY LABORATORY CONSORTIUM

U.S. DEPARTMENT OF ENERGY SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

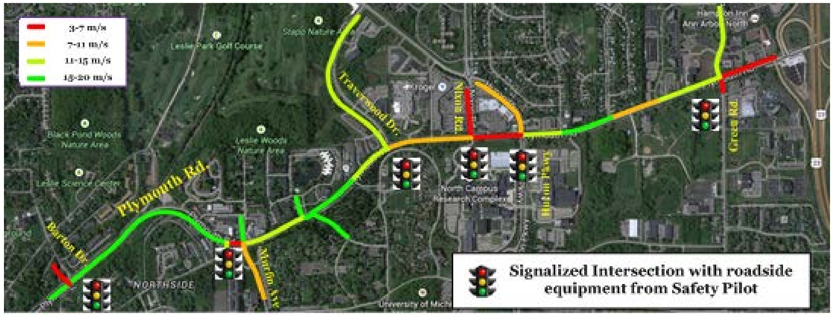
Multi-Year, Multi-Lab Effort (3 years, 5 labs)

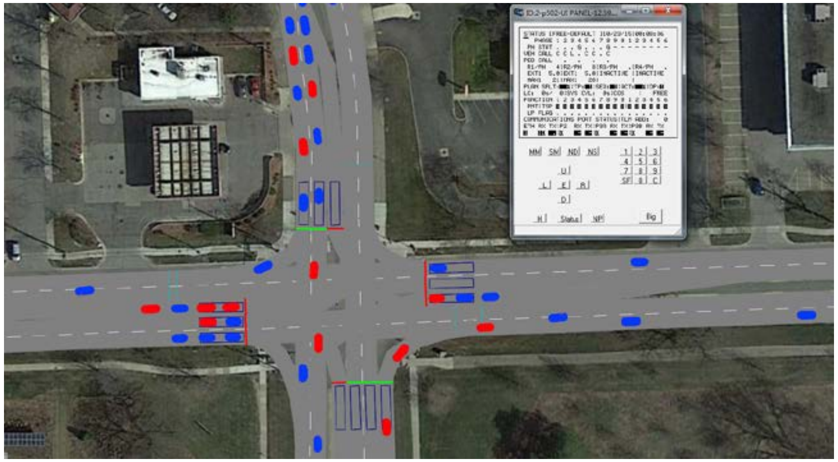
- Energy implications of connectivity & automation
- Multi-modal transport of people and goods
- City-scale urban mobility models for planning
- Informed fueling infrastructure investments
- Understanding consumer mobility decisions

Critical Research Questions:

- What are the energy, technology, and usage implications of connected & autonomous technologies?
- How will these systems operate in the real world?
- What are the critical levers to promote "eco-CAV" solutions?

Designing for the nexus of safety, energy, and mobility





MOBILITY DECISION SCIENCE

Critical Research Questions

- What are the transportation energy impacts of potential lifestyle trajectories?
- How do consumers and companies make travel decisions in the short / medium / long-term?
- What mechanisms are available to influence consumer decisions?

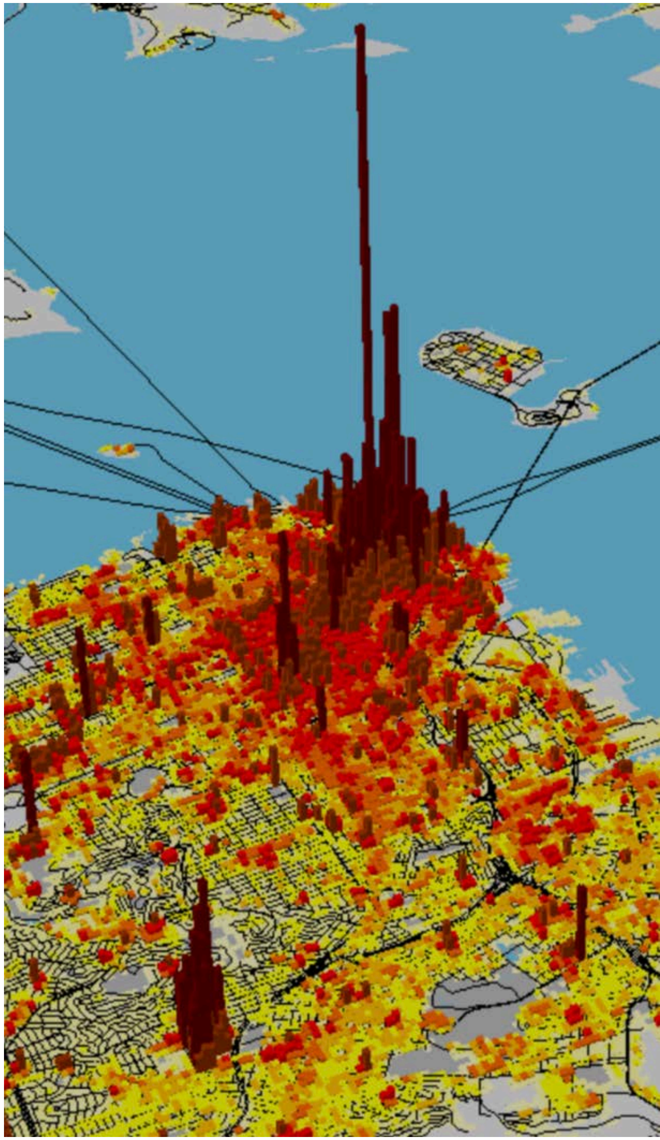
Technology and policy that anticipate how decisions are made

U.S. DEPARTMENT OF ENERGY SMARTMOBILITY Systems and Modeling for Accelerated Research in Transportation

Critical Research Questions

- How will SMART-enabled mobility impact the urban traveler in terms of VMT, congestion, vehicle ownership, mobility-as-a-service?
- What are the long-term impacts on the urban built environment?
- What are the energy impacts of optimized signal management and automated mobility districts?

Providing scientific support to decision makers

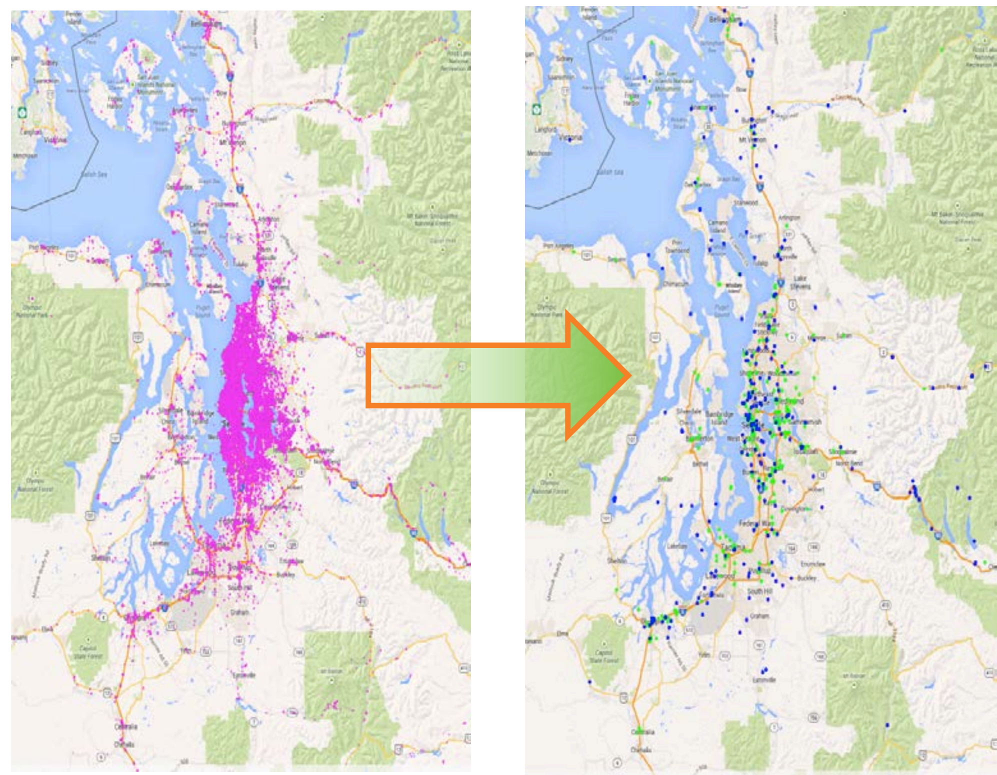


ADVANCED FUELING INFRASTRUCTURE

Critical Research Questions

- What infrastructure is required to support future mobility systems?
- How can next-gen fueling/charging infrastructure enable low-carbon transportation?
- What are the costs and benefits, and where should infrastructure investments be made?

Mapping EV Technology with Travel Patterns Reduced EVSE Locations from 18,000+ to 281 in Seattle



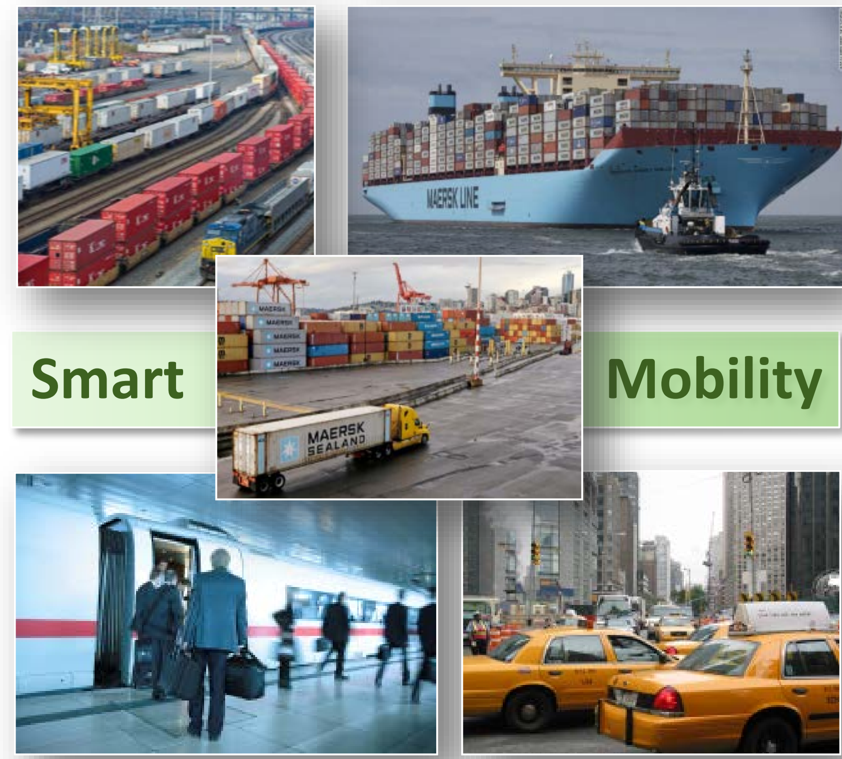
Informed infrastructure investments that drive consumer adoption

EEMS003

MULTI-MODAL TRANSPORTATION

<u>Critical Research Questions</u>

- What are the potential energy benefits of reduced modality interface barriers?
- What are the interactions between mass transit and transportation network companies?
- What opportunities do evolving household spending and commodity flow bring for freight logistics?



Energy-efficient, seamless multi-modal transport of people and goods

EEMS BUDGET – PAST & PRESENT

Funding in millions	**FY 2016** Enacted	**FY 2017** Enacted
Energy Efficient Mobility Systems	$5.5	$16.4

- Energy Efficient Mobility Systems is funded through Analysis and Vehicle Systems Program funds in FY 16/17.

- The FY2018 Budget Request represents a dedicated EEMS Budget Line Item.

EEMS PARTNERSHIPS

Coordination with:

- ITS-JPO
- FTA
- FHWA
- OST-R
- VOLPE

Coordination with:

- TRANSNET
- NEXTCAR

Established:

- EEMS Working Group

Initiated Discussion:

- EEMS & 21CTP

Stakeholder Engagement & Technical Assistance:

- Living Labs
- Technologist-in-Cities Pilot

ACCOMPLISHMENT: Advanced Control of CAVs (EEMS016)

Connectivity
Cloud, Digital Maps, V2V, V2I

Sensing + Vision

Future road information
speed limits, grade, traffic lights, preceding vehicles, traffic, etc.

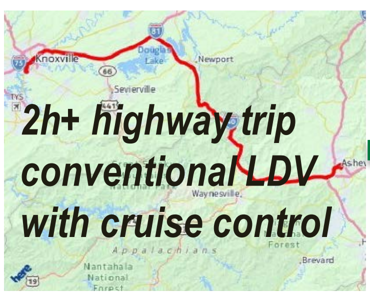
Automation

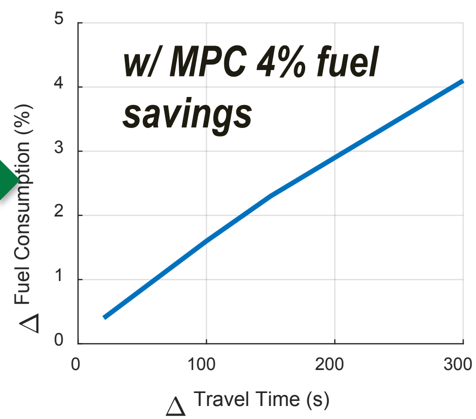
Intelligent Energy-Efficient CAV

Electrification
+ other advanced powertrain tech

1. Advanced Control

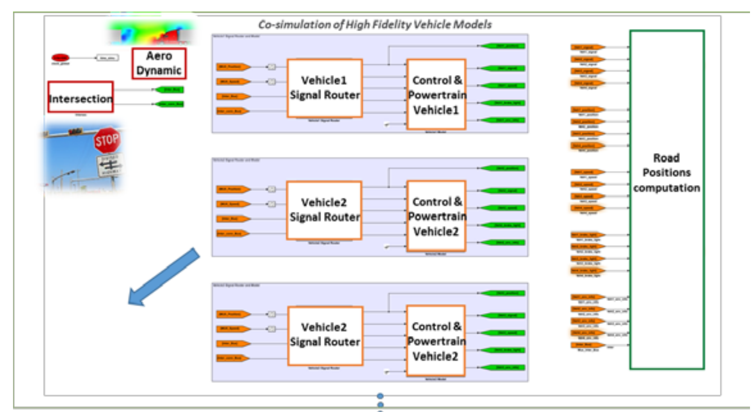
Optimized speed and powertrain operations, using optimal control theory and model-predictive control (MPC)





2. CAV + Environment Modeling Framework

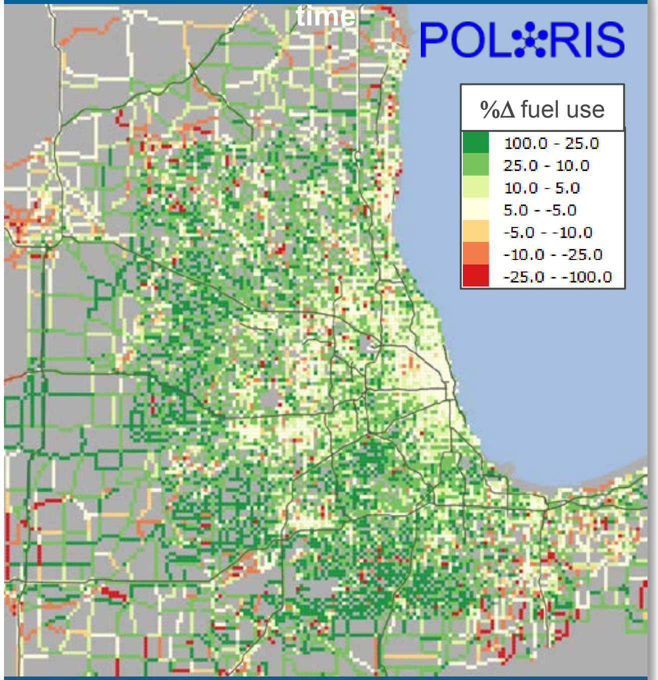
Simulated a broad range of driving situations, powertrains and CAV technologies



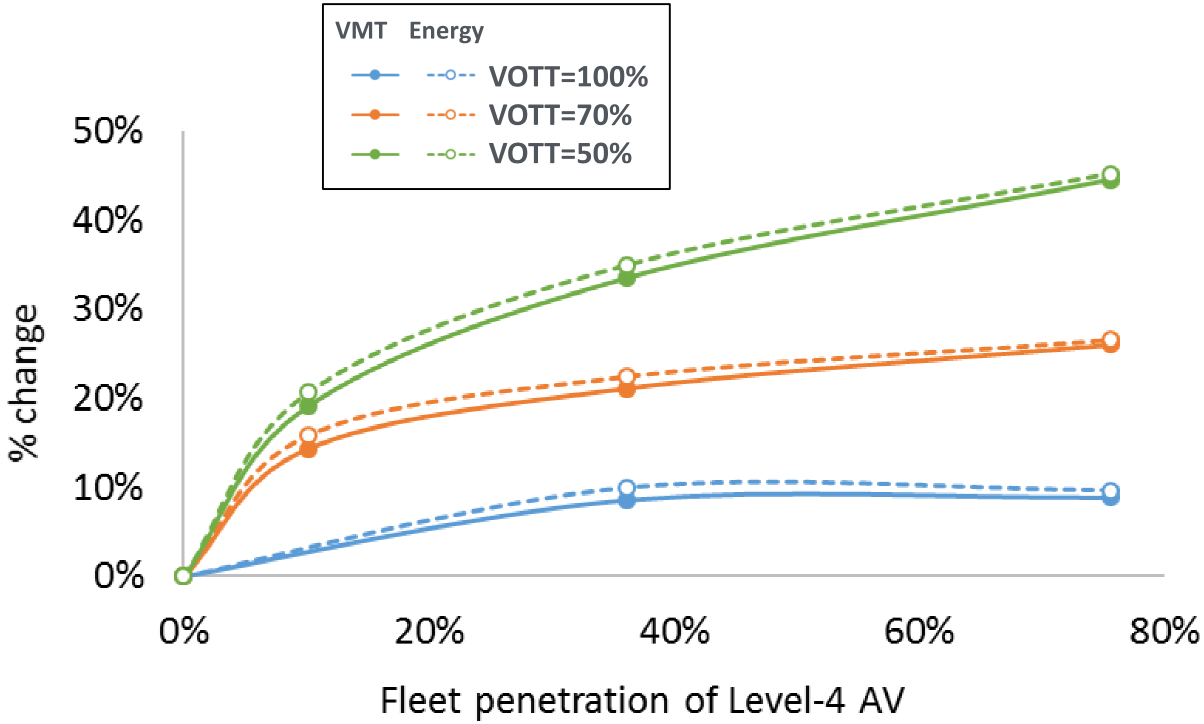
ACCOMPLISHMENT: Regional CAVs Energy Use (EEMS017)

- Evaluated CAV adoption and effect on travel demand and traffic flow
- Benefits due to improved traffic flow offset by increased VMT due to induced demand
- VMT increases with CAVs market penetration and reduced value of travel time (VOTT)
- Fuel consumption increased over 43% in worst case scenario

Comparison of low and high penetration fuel use at 70% of current value of travel time

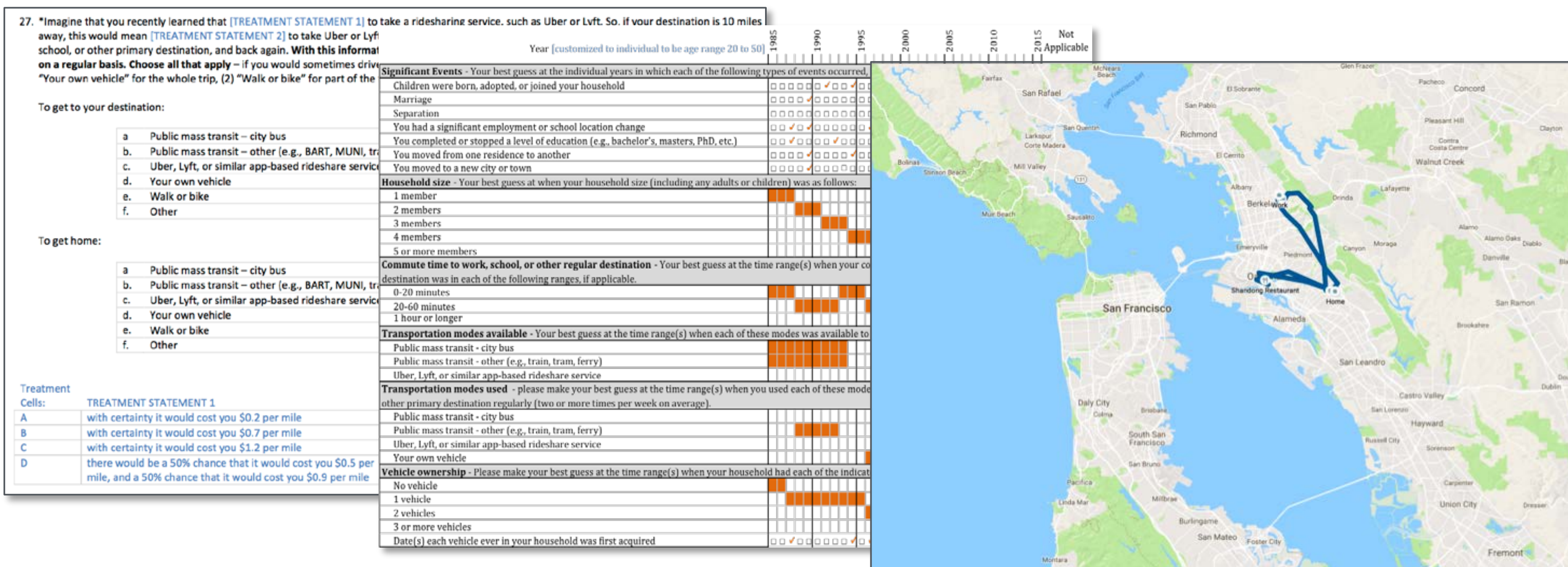


Dark green areas indicate higher fuel consumption in high penetration scenario



ACCOMPLISHMENT: WholeTraveler Behavior Study (EEMS023)

- Designed two-phase survey with innovative features
  - Life History Calendar
  - Inexpensive and efficient GPS data collection
  - Ability to compare stated and revealed preferences
  - Creative experimental questions to understand preferences and transportation megatrends



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

ACCOMPLISHMENT: Modeling & Data Workshops (EEMS007)

- SMART Mobility Modeling & Simulation Tools Workshop, Nov 2016 at ORNL
- SMART Mobility Transportation Data Workshop, May 9–10, UC Berkeley
- Model and Data Curation across the Smart City Finalists, Fall 2017

✓ *Leading Academic, Industry and Public partners engaged*
✓ *Seven Smart City Finalist cities represented*
✓ *Complement DOE Lab consortium with national transportation experts*

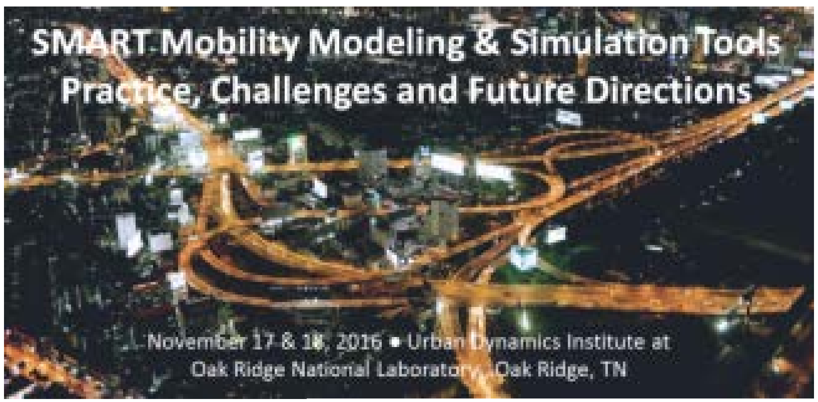


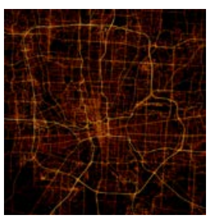

Photo courtesy of ORNL

ACCOMPLISHMENT: Emulated Car-Sharing Demand (EEMS012)

Method for emulating shared mobility vehicle data

- Modeling advanced fueling infrastructure requires spatially-resolved vehicle activity patterns
- Despite the proliferation of shared mobility companies, access to shared mobility data is limited
- AFI team developed algorithms to synthesize car-sharing vehicle trajectories from personal vehicle GPS trajectories
- Real-world car-sharing data obtained from ReachNow – will be used to validate emulated data

Real-world travel profiles



Transportation Secure Data Center

NREL

Rescheduling algorithms to emulate car sharing, ride sharing, or ride hailing

Car-sharing preliminary results: scenario 1.i)

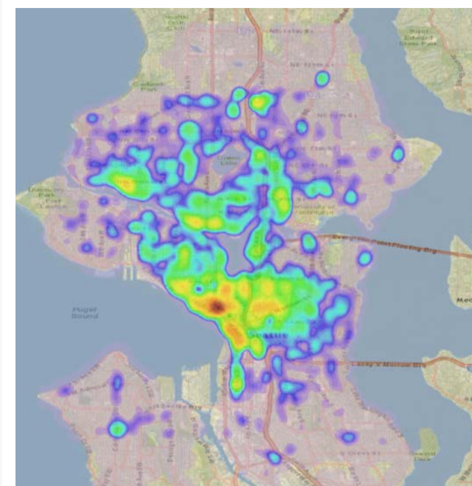
1.i) Free floating scenario w/o relocation and unlimited size fleet

Table 1.1 Synthetic Austin TX car-sharing trip results (*1363 trips-231 drivers*)

	Personal car	Shared Car synthetic data y=0.1 miles	Shared Car synthetic data y=0.25 miles	*acceptable walking distance
Total Vehicle Count	231	296	333	
Trip Count	1363 (constant in all cases); avg. trips per person 5.9			
Avg VMT per person	22.27 (constant in all cases)			
% car-sharing trips	0	43.8%	53.41%	*of trips that are used by drivers in car-sharing
Car sharing vehicles	0	153	212	*used by individuals who are not operating personal cars
Users of car share	n.a.	88	110	*of all drivers population
Avg # users/shared car/per day	n.a.	1.32	1.31	*of single occupancy car/day
Avg VMT/shared car/day	n.a.	12.93	11.39	*refer to total avg. VMT/day
Avg VMT/personal car/day	22.27	22.71	22.84	
Avg shared car VMT/trip	n.a.	3.49	3.39	*refers to avg. VMT/trip
Avg personal car VMT/trip	3.78	4.00	4.20	

Data sources: Transportation Secure Data Center. (2017). National Renewable Energy Laboratory. Accessed February 15, 2017: *www.nrel.gov/tsdc*. 3

Preliminary Results



ReachNow free-floating car-sharing vehicle parking density in Seattle, WA May 2016 to Feb 2017

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

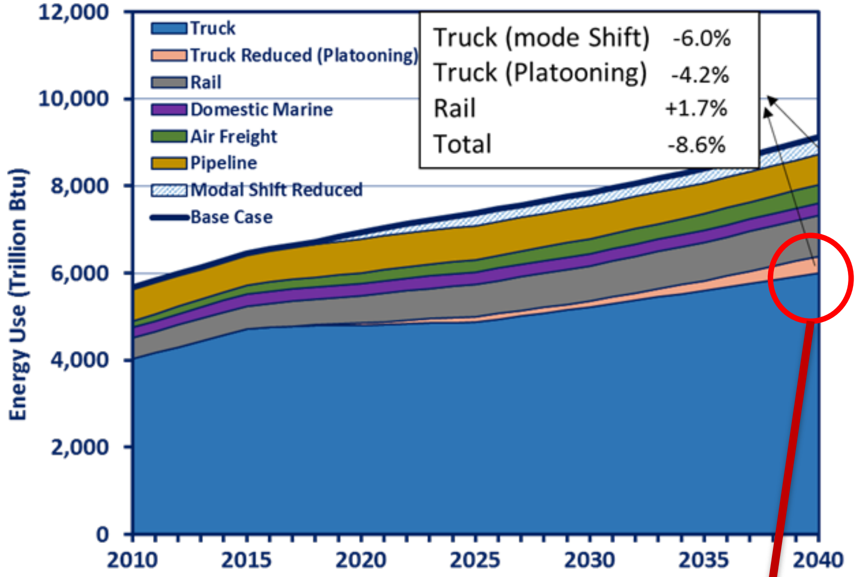
ACCOMPLISHMENT: Quantified Platooning Potential (EEMS025)

Completed initial assessment of national energy and emission impacts:

Platooning may significantly cut inter-city freight energy use

Conclusions:

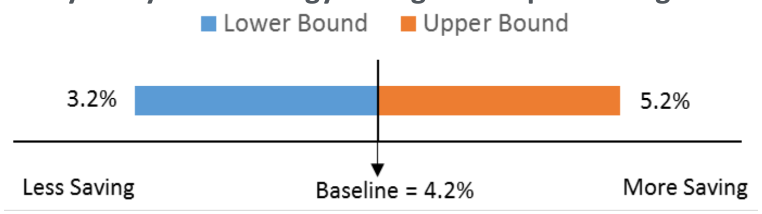
- Cumulative freight sector total energy saving (2016-2040) due to truck platooning could be up to 5.3 Quad BTU (upstream included)
- Annual freight energy consumption could be reduced by ~ 5% due to truck platooning in 2040
- Earlier analysis indicates mode shift from truck to rail could reduce annual truck energy consumption by additional 6% in 2040



Method and Assumptions

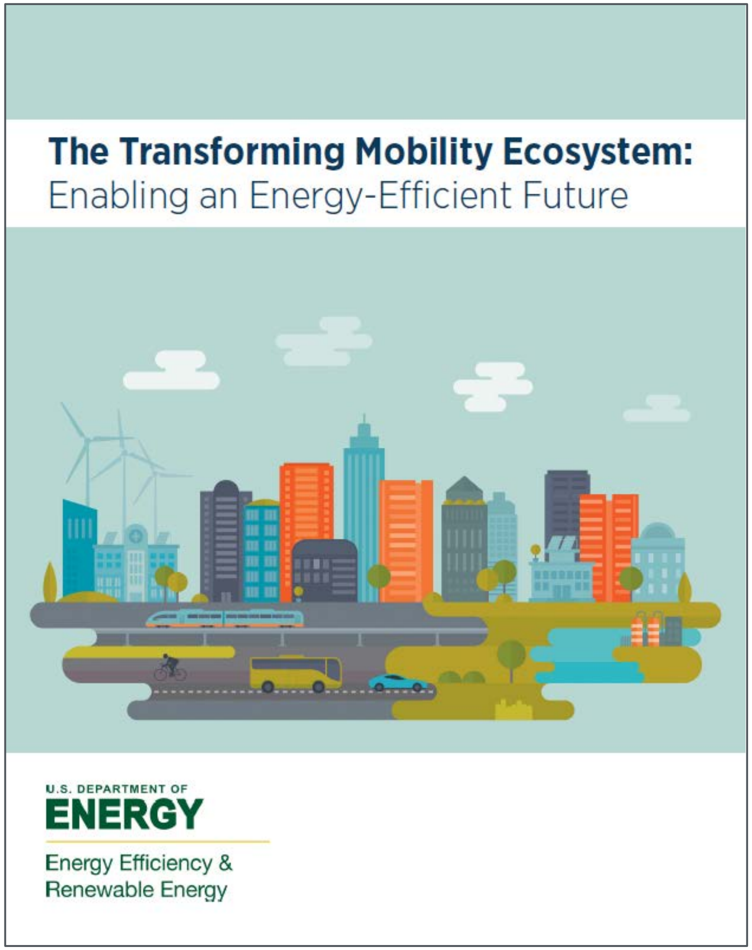
- Use Argonne's **NEAT** model which captures freight energy saving by commodity type, mode and length of haul.
- Platoonable ton-miles increase from 0% to 65% over the time horizon of 2016 ~ 2040
- Energy intensity (BTU/ton-miles) decrease 4% for leading trucks and 10% for following trucks. (On average, one leading truck is followed by 3 following trucks.)
- Sensitivity analysis: the platoonable ton-miles varies from 50% ~ 80% at 2040

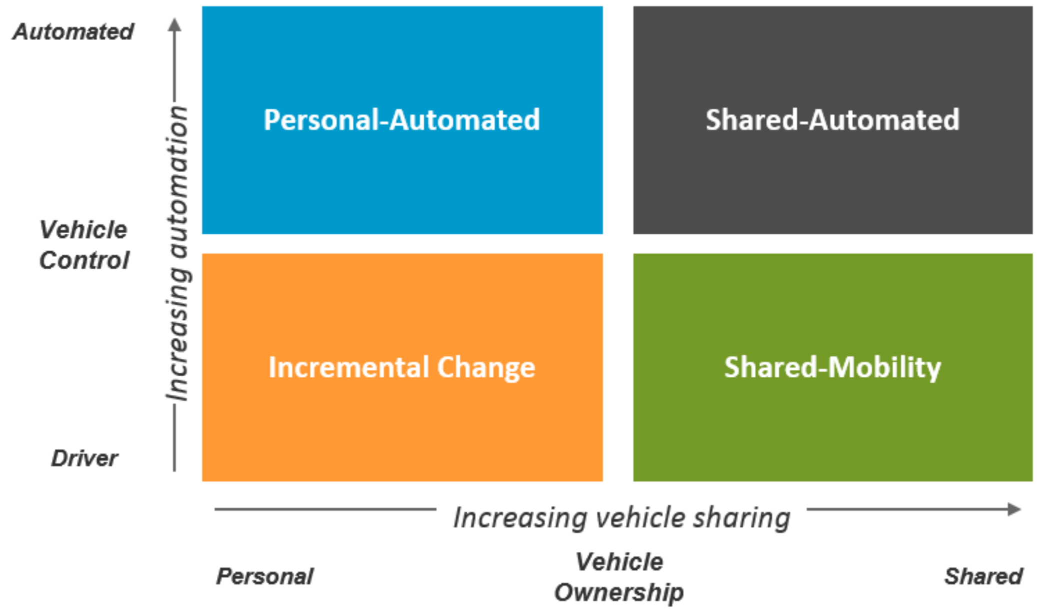
Sensitivity analysis for energy saving due to platooning at 2040



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

EEMS REPORTS: TRANSFORMING MOBILITY ECOSYSTEM

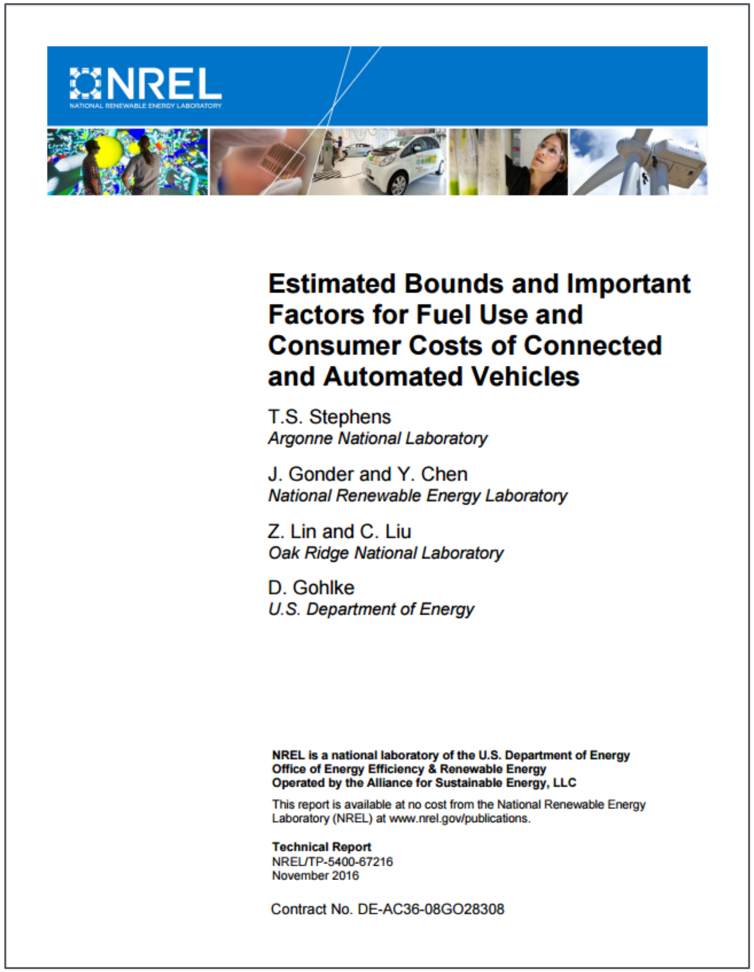




*How do we move forward to achieve aspirational outcomes for the **economy, safety, affordability, accessibility**, and **energy-efficient mobility**?*

 https://energy.gov/eere/vehicles/downloads/transforming-mobility-ecosystem-report

EEMS REPORTS: ESTIMATED BOUNDS OF CAV FUEL USE


NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles

T.S. Stephens
Argonne National Laboratory

J. Gonder and Y. Chen
National Renewable Energy Laboratory

Z. Lin and C. Liu
Oak Ridge National Laboratory

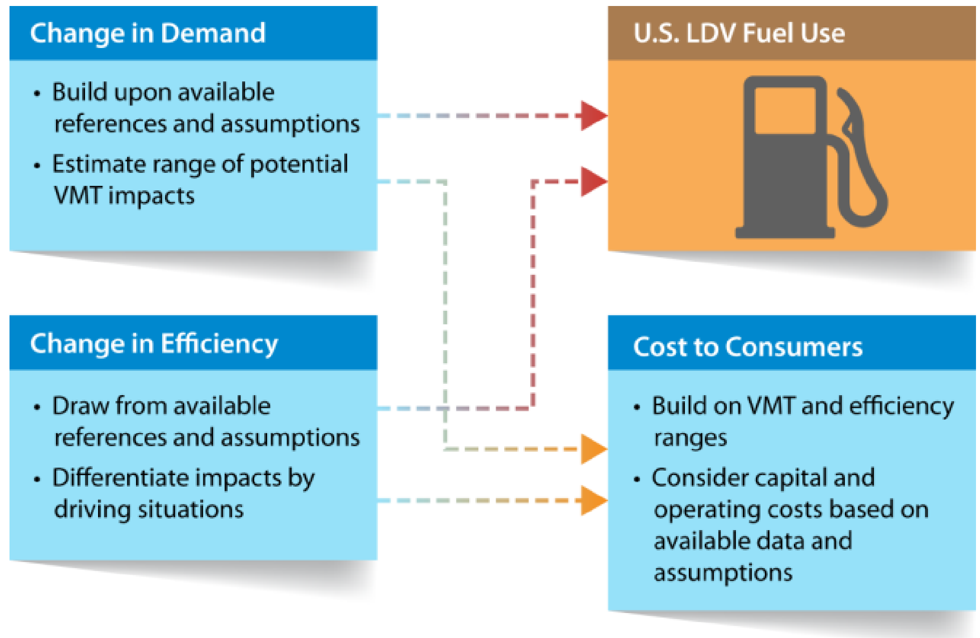
D. Gohlke
U.S. Department of Energy

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Technical Report
NREL/TP-5400-67216
November 2016

Contract No. DE-AC36-08GO28308



The potential factors affecting future CAV use, energy consumption, and costs - and the nature of their influence - are highly uncertain.

EEMS SELECTED REPORTS

- Muratori, M., Holden, J., Lammert, M., Duran, A., Young, S., and Gonder, J., "Potentials for Platooning in U.S. Highway Freight Transport," SAE Int. J. Commer. Veh. 10(1):2017, doi:10.4271/2017-01-0086.
- Rios-Torres, J., and Malikopoulos, A. A. 2017. “Automated and Cooperative Vehicle Merging at Highway On-Ramps.” 2017 Transportation Research Board Annual Meeting January 8, 2017 Washington, D.C.
- Andreas Malikopoulos, Seongah Hong, Joyoung Lee, Brian Park. Development and Evaluation of Speed Harmonization using Optimal Control Theory: A Simulation-Based Case Study at a Speed Reduction Zone. 2017 Transportation Research Board Annual Meeting January 8, 2017 Washington, D.C.
- Rios-Torres, J., and Malikopoulos, A.A., "Energy Impact of Different Penetrations of Connected and Automated Vehicles: A Preliminary Assessment," in Proceedings of the 9th ACM SIGSPATIAL International Workshop on Computational Transportation Science, 2016.

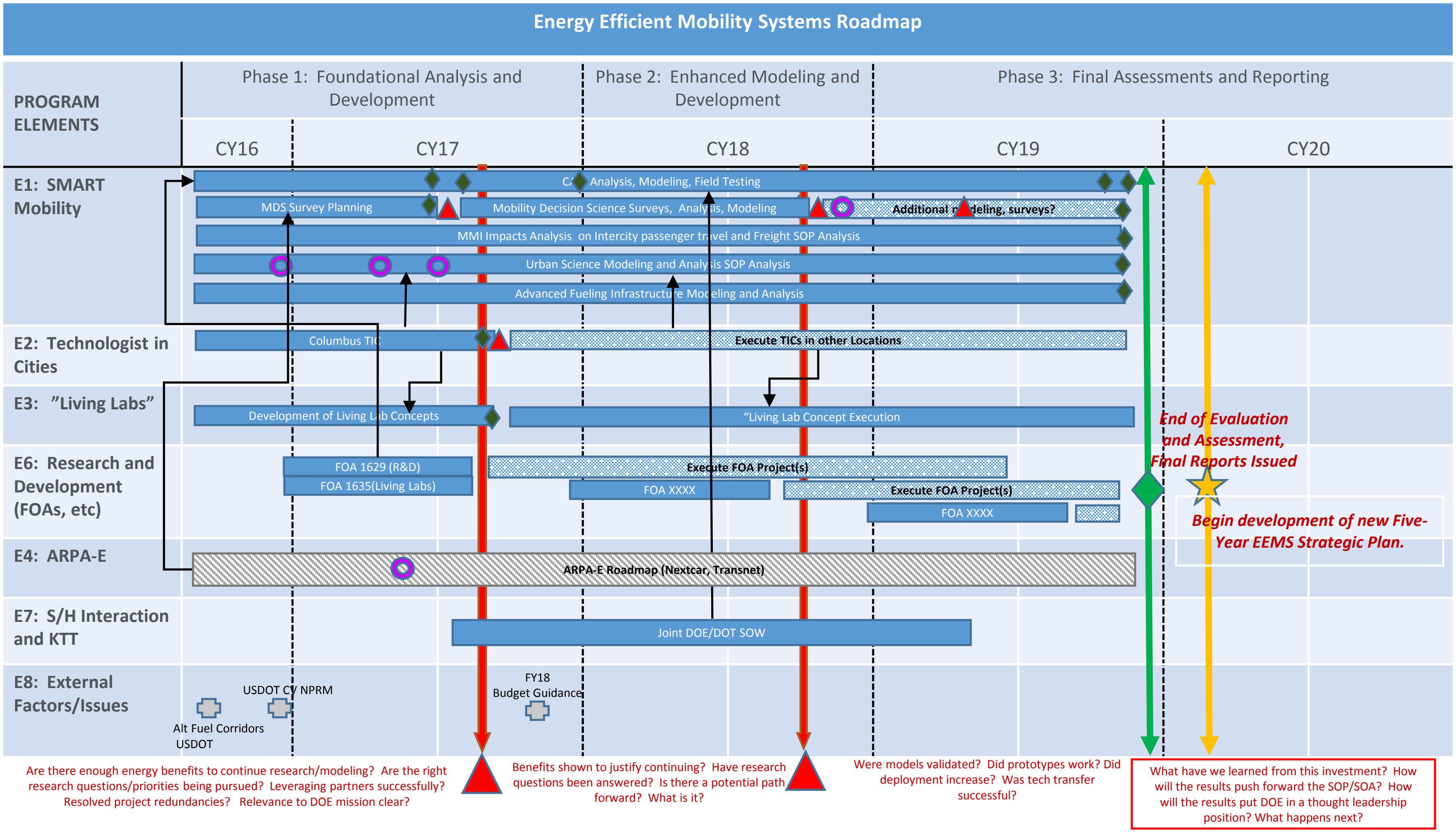
EEMS SELECTED REPORTS

- Auld, J., V. Sokolov, T. Stephens (2017). Analysis of the Impacts of CAV Technologies on Travel Demand. Transportation Research Record: Journal of the Transportation Research Board, No. 2625
- "Analysis and Measurement of Time-Use and Time Value of Travel in the context of Emerging Mobility Technologies, Report 1: Purpose and Plan For Data Gathering," DRAFT 3/31/2017, Paul N. Leiby (ORNL), Joshua Auld (ANL), Taha Rashidi (Univ. New South Wales), Jonathan D. Rubin (Univ. of Maine)
- Yang, J., J. Dong, Z. Lin and L. Hu "Predicting market potential and environmental benefits of deploying electric taxis in Nanjing, China", Transportation Research, Part D, 49, 68-81 (2016). http://dx.doi.org/10.1016/j.trd.2016.08.037
- Eleftheria (Ria) Kontou, Zhenhong Lin, Changzheng Liu, Yafeng Yin. "Public Charging Opportunity Frontiers for U.S. Cities". Presented at TRB Annual Meeting, Washington DC, Jan 2017.
- Auld, J., D. Karbowski, V. Sokolov, "Assessing the regional energy impact of connected vehicle deployment", World Conference on Transport Research (WCTR), Shanghai, 10-15 July 2016.

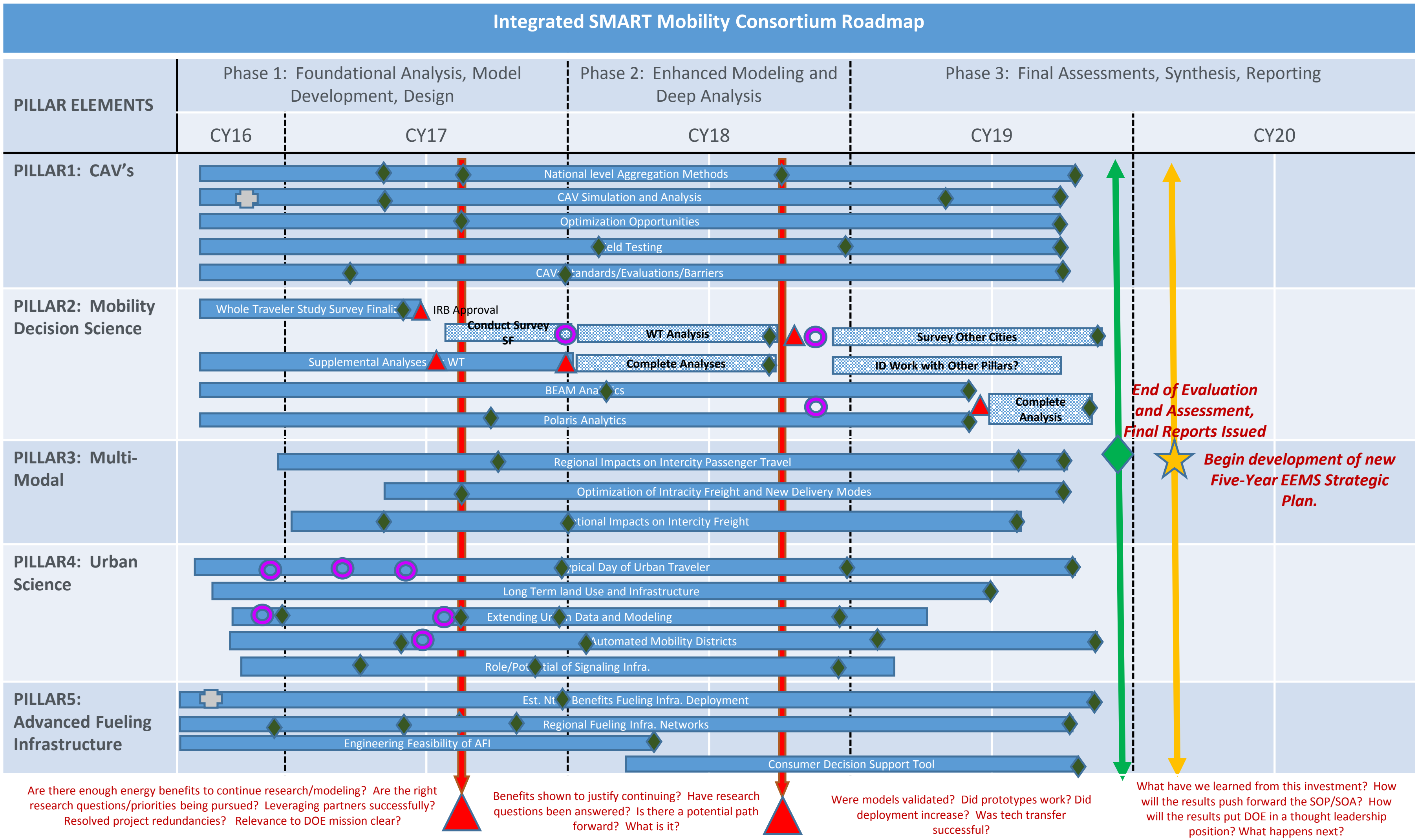
EEMS SELECTED REPORTS

- Aziz, H.M.A., Wang, H., Young, S., Sperling, J., Bhaduri, B., 2017. Opportunities and Challenges in Traffic Signal Operations and Infrastructure Deployment in the Era of Connected and Automated Vehicles, in: ITE/CITE 2017 Conference, Annual Meeting of the Institute of Transportation Engineers. Toronto, Canada, August 2017.
- ITS-World Congress. A Convergence of Public-Private Benefits in Denver, USA: Surveys and Analysis to Inform Urban Mobility, Energy, and Infrastructure-Related Innovation. [Paper accepted for presentation on April 27, 2017]
- ITS-World Congress. Exploring an Energy-Mobility Nexus: A Framework for Curating and Comparing Data and Models Using Case Studies of Four 'Smart City' Finalists. [Paper accepted for presentation on April 27, 2017]
- Y. Zhou, "National Scale Multi-Modal Energy and GHG Analysis of Inter-City Freight"
- Young S.E, Hou, Y., Garikapati, V., Chen, Y., and Zhu, L. (2017). Initial Assessment and Modeling Framework Development for Automated Mobility Districts, *ITS-World Congress* (Paper Accepted for Presentation).

EEMS – PROGRAM ROADMAP UNDER DEVELOPMENT



SMART MOBILITY ROADMAP UNDER DEVELOPMENT



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

CONCLUSION

- ***Major disruption*** occurring in transportation
- ***Connected & Autonomous Vehicles*** (CAVs) are coming
- CAVs & Shared Mobility have ***dramatic implications for energy use***
- VTO's ***EEMS Program is tackling the challenge*** head-on
- Come to the ***EEMS sessions Wed/Thurs*** to hear more

A Maximum-Mobility, Minimum-Energy Future

CONTACT

David L. Anderson

david.anderson@ee.doe.gov

(202) 287-5688